

International Vehicle Emissions (IVE) Model

Clean Cities Conference

May 20, 2003

Palm Springs, CA

IVE Modeling Goals

- **Define low-cost, easy to use methodologies for developing key motor vehicle related data.**
- **Provide a sophisticated model that is:**
 - Flexible and easy to use. (e.g. Living Model)
 - Adaptable to multiple international locations.
 - Useful for analyzing policy decisions and vehicle growth impacts.
 - Provides a broad range of criteria, toxic, and global warming pollutant data.

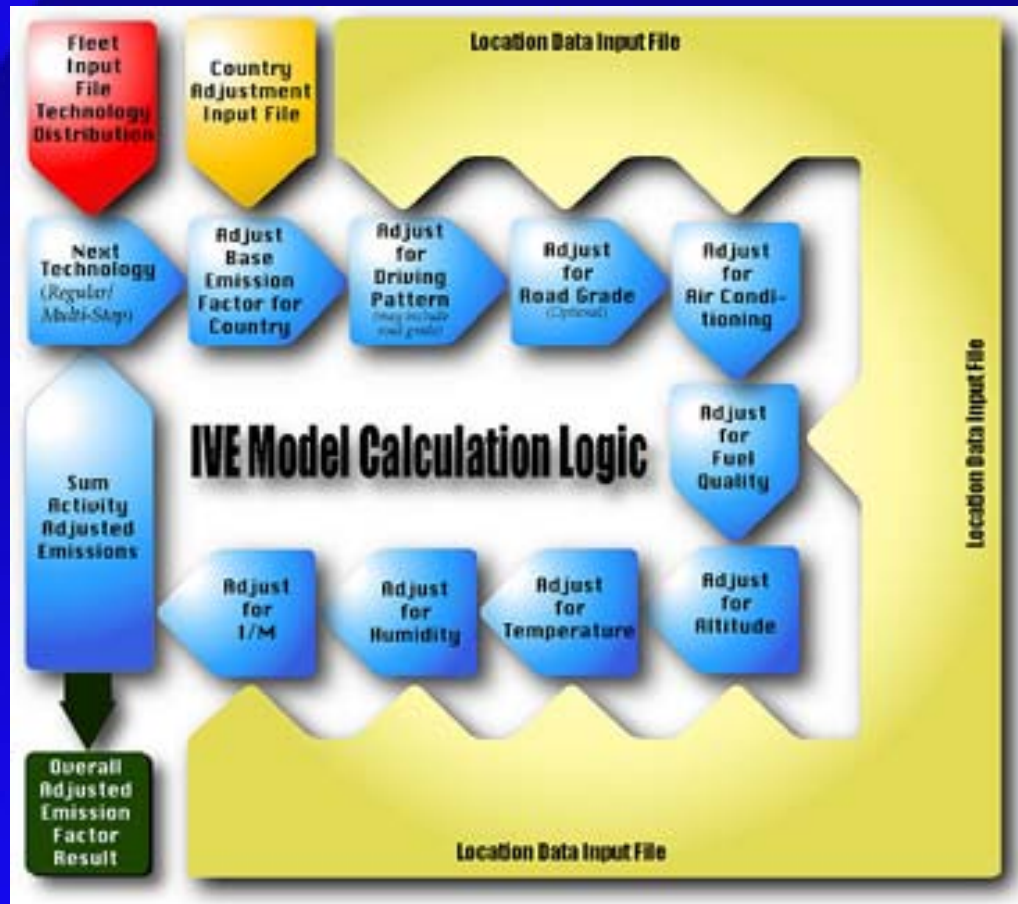
Existing General Vehicle Emission Models

- **USEPA, Europe, California**
- **Existing models designed for specific use in US, Europe, and California**
- **Inaccurate when applied to most situations outside of their intended use areas.**

IVE Model Uses 3 Key Input Files

- **Location file describes applicable**
 - Altitude, road grade(optional), temperature, humidity
 - Diesel and gasoline fuel quality
 - Driving and start patterns and amounts
- **Fleet file describes applicable**
 - Distribution of vehicle technologies (2 X 1243)
 - Allows two classes of vehicle fleets (Normal Use and Multi-stop vehicles)
- **Country adjustment file describes applicable**
 - Adjustments to base emission factors

Model Calculation Process



Location Page

- **Specifies data pertaining to the immediate location including**
 - General Information such as average altitude, type of I/M program if any, fraction of persons using a/c at 80 deg F, fossil fuel characteristics.
 - Hourly (or daily) data including driving patterns, average speeds, travel distance or time, temperature, humidity, start patterns, number of starts

Location Page

IVE Model 0.6.0

File

International Vehicle Emissions Model

Calculation

Location

Fleet

Base Adjustments

Location

SantiagoARTAIL

Day

03

Month

May

Year

2002

Interpolation

Fleet

Santiago - Overall Fleet 2002

Day of the week

Friday

Altitude

0.0

meters

A/C Use at 27°C (80°F)

0.0

%

Base Adjustment

- none -

I/M Class

none

Road Grade

0.0

%

Fuel Characteristics

Gasoline

Overall

moderate/premix...

Sulfur (S)

moderate

Lead (Pb)

none

Benzene

moderate

Oxygenate

0%

Diesel

Overall

moderate

Sulfur (S)

moderate

Hour

0:00

Computer generated

User entered

Humidity

50.0

%

Temperature

20.0

°Celsius

Distance/Time

1.0

kilometers

Start-ups

1.0

Standard

Multi-stop

FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8	FC9	FC10
				0.1	0.2	0.4	0.7	1.6	2.9
FC11	FC12	FC13	FC14	FC15	FC16	FC17	FC18	FC19	FC20
5.6	40.2	14.2	10.0	5.1	1.8	0.5	0.1		
FC21	FC22	FC23	FC24	FC25	FC26	FC27	FC28	FC29	FC30
							0.1	0.2	0.3
FC31	FC32	FC33	FC34	FC35	FC36	FC37	FC38	FC39	FC40
0.7	2.5	5.7	4.8	1.8	0.4	0.1			
FC41	FC42	FC43	FC44	FC45	FC46	FC47	FC48	FC49	FC50
FC51	FC52	FC53	FC54	FC55	FC56	FC57	FC58	FC59	FC60
0.25	0.5	1	2	3	4	6	8	12	18

Average Velocity

30.0

km/hr

Total

100.0

%

Driving Style Distribution

Total

0.0

%

Soak Time Distribution

Fleet Technologies

- **The IVE model allows selection of up to 1243 technologies categorized by vehicle type, size, fuel type, age and emissions control technology**
- **Several Default files are created for the IVE models from the MOBILE6 data**
- **Data has been collected in several international areas**

Vehicle Technology Classifications

IDE Model Development

Light Duty Gasoline Vehicles		Light Duty Diesel Vehicles		Light Duty Vehicles (Ethanol, Natural Gas, Propane, retrofits, etc)		Heavy Duty Gasoline Vehicles		Heavy Duty Diesel Vehicles		Heavy Duty Vehicles (Ethanol, Natural Gas, Propane, etc)		Gasoline and Ethanol Motorcycles	
Carburetor	None	Pre-Chamber Inject.	None	Carburetor / Mixer	None	Carburetor	None	Pre-Chamber Inject.	None	Carburetor	None	2-Cycle, FI	None
Carburetor	2-Way	Pre-Chamber Inject.	Improved	Carburetor / Mixer	2-Way	Carburetor	2-Way	Direct Injection	Improved	Carburetor	2-Way / EGR	4-Cycle, Carb	None
Carburetor	2-Way / EGR	Direct Injection	EGR+	Carburetor / Mixer	2-Way / EGR	Carburetor	2-Way / EGR	Direct Injection	EGR+	Carburetor	3-Way / EGR	4-Cycle, Carb	Catalyst
Carburetor	3-Way	FI	PM	Carburetor / Mixer	3-Way	Carburetor	3-Way	FI	PM	FI	3-Way / EGR	4-Cycle, FI	None
Carburetor	3-Way / EGR	FI	PM/NOx	Carburetor / Mixer	3-Way / EGR	Carburetor	3-Way / EGR	FI	PM/NOx			4-Cycle, FI	Catalyst
Single-Pt FI	none	FI	EuroI	Single-Pt FI	2-Way	FI	none	FI	EuroI				
Single-Pt FI	none / EGR	FI	EuroII	Single-Pt FI	2-Way / EGR	FI	2-Way	FI	EuroII				
Single-Pt FI	2-Way	FI	EuroIII	Single-Pt FI	3-Way	FI	2-Way / EGR	FI	EuroIII				
Single-Pt FI	2-Way / EGR	FI	EuroIV	Single-Pt FI	3-Way / EGR	FI	3-Way	FI	EuroIV				
Single-Pt FI	3-Way	FI	Hybrid	Multi-Pt FI	3-Way	FI	3-Way / EGR	FI	EuroV				
Single-Pt FI	3-Way / EGR			Multi-Pt FI	3-Way / EGR	FI	EuroI	FI	Hybrid				
Multi-Pt FI	none			Multi-Pt FI	3-Way / EGR	FI	EuroII						
Multi-Pt FI	none / EGR				ZEV	FI	EuroIII						
Multi-Pt FI	3-Way					FI	EuroIV						
Multi-Pt FI	3-Way / EGR					FI	EuroV						
Multi-Pt FI	3-Way / EGR												
Multi-Pt FI	LEV												
Multi-Pt FI	ULEV												
Multi-Pt FI	SULEV												
Multi-Pt FI	EuroI												
Multi-Pt FI	EuroII												
Multi-Pt FI	EuroIII												
Multi-Pt FI	EuroIV												
Multi-Pt FI	Hybrid												

Each Technology Classification

- **Has three size groups associated with it.**
- **Has three use groups associated with it.**
- **Thus, there are 9 sub-groups for each technology classification.**
- **There are also 45 user defined technologies.**
- **Two technology groups are used. One is for normal vehicles and the second is for multi-stop vehicles.**

Fleet Page

IVE Model 0.6.0

File

International Vehicle Emissions Model

Calculation

Location

Fleet

Base Adjustments

Fleet

Hour

Santiago - Overall Fleet 2002

0:00

Add Technology

0 Auto/SmTik:Petrol:LtWt:Carb:NoCat:PCV:LwUse

Index	Technology	Standard	Multi-stop	Standard AC	Multi-stop AC
125	Auto/SmTik:Petrol:HvWt:MultiPtFI:3Way:PCV:HiUse	0.1			
124	Auto/SmTik:Petrol:HvWt:MultiPtFI:3Way:PCV:MdUse	0.69		57.14	
123	Auto/SmTik:Petrol:HvWt:MultiPtFI:3Way:PCV:LwUse	1.96		90.0	
122	Auto/SmTik:Petrol:MdWt:MultiPtFI:3Way:PCV:HiUse	1.37	4.95	35.71	
121	Auto/SmTik:Petrol:MdWt:MultiPtFI:3Way:PCV:MdUse	12.24	2.7	46.4	
120	Auto/SmTik:Petrol:MdWt:MultiPtFI:3Way:PCV:LwUse	24.94	0.9	50.2	
119	Auto/SmTik:Petrol:LtWt:MultiPtFI:3Way:PCV:HiUse	0.78			
118	Auto/SmTik:Petrol:LtWt:MultiPtFI:3Way:PCV:MdUse	7.05		6.94	
117	Auto/SmTik:Petrol:LtWt:MultiPtFI:3Way:PCV:LwUse	11.75		18.33	
71	Auto/SmTik:Petrol:HvWt:SingPtFI:2Way:PCV:HiUse	0.2		50.0	
70	Auto/SmTik:Petrol:HvWt:SingPtFI:2Way:PCV:MdUse	0.1		100.0	
69	Auto/SmTik:Petrol:HvWt:SingPtFI:2Way:PCV:LwUse	0.1		100.0	
68	Auto/SmTik:Petrol:MdWt:SingPtFI:2Way:PCV:HiUse	0.39		25.0	
67	Auto/SmTik:Petrol:MdWt:SingPtFI:2Way:PCV:MdUse	0.98		10.0	
66	Auto/SmTik:Petrol:MdWt:SingPtFI:2Way:PCV:LwUse	0.2		50.0	
65	Auto/SmTik:Petrol:LtWt:SingPtFI:2Way:PCV:HiUse				
64	Auto/SmTik:Petrol:LtWt:SingPtFI:2Way:PCV:MdUse	0.49		20.0	
63	Auto/SmTik:Petrol:LtWt:SingPtFI:2Way:PCV:LwUse	0.1			
8	Auto/SmTik:Petrol:HvWt:Carb:NoCat:PCV:HiUse	0.78			

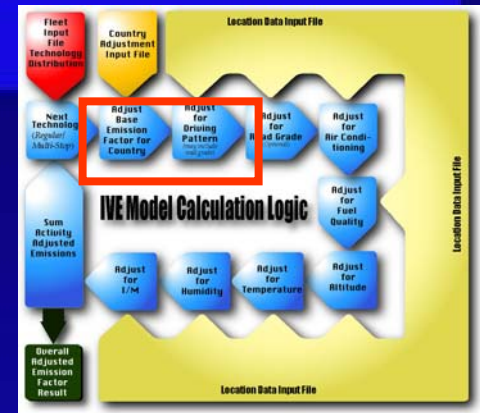
85.69% + 14.31% = 100.0%

Normalize

Load Effects (Road Grade and A/C)

- Road Grade can either be modeled Directly through the use of the driving patterns or a constant road grade for the entire link may be applied in the Location File. Valid grade inputs range from -14 to $+14\%$
- The change in Vehicle Specific Power associated with Road Grade and A/C use is applied to the driving corrections.
- The fraction of travel in each VSP bin is prorated for each bin.

Example: user inputs road grade of 2% and average velocity of 15m/s \Rightarrow $+2.9\text{kW/ton}$ VSP increase. Since each VSP bin range is 4.1kW/tons , the model would move 72% of the fleet up a bin.



International Vehicle Emissions (IVE) Model

TECHNICAL BACKGROUND

Emissions Broken Into Two Categories

- **Start-up emissions**

- Excess emissions beyond normal hot-running emissions that occur while engine is warming up.
- Occur typically in the first 200 seconds of vehicle operation.

- **Running emissions**

- Those emissions that occur during vehicle operations including idle.
- There are both running and start-up emissions during the first 200 seconds of vehicle operation.

How the Base Emission Rates are Developed:

- **Most Gasoline and Diesel Vehicles:**
 - EPA MOBILE6 and ARB EMFAC model documentation
- **Most Small Engine (Motorcycles):**
 - Government of India, World Bank Asian Documents, and Thailand
- **Alternative Fueled Vehicles:**
 - EPA Alternative Fuels Data Center and Department of Energy
 - Compared relative to gasoline counterpart
- **New Information Continually Added**

Base Emission Rates For CNG/Propane Vehicles

Technology Sources	Natural Gas Retrofit/Flex		Propane Retrofit/Flex	
	Natural Gas	Fuel	Propane	Fuel
	ANL, NREL	DOE3, NREL	DOE4, ANL	DOE4, ANL
VOC	0.20	0.30	0.50	0.60
CO	0.70	1.00	0.70	2.00
NO _x	0.80	1.00	0.95	2.60
PM	0.05	0.90	0.10	0.90
Lead	0.00	0.00	0.00	0.00
SO ₂	0.02	0.02	0.02	0.02
NH ₃	1.00	1.00	1.00	1.00
1,3 butadiene	0.01	0.01	0.01	0.01
Formaldehyde	1.16	1.16	1.16	1.16
Acetaldehyde	0.35	0.35	0.35	0.35
Benzene	0.03	0.03	0.03	0.03
CO ₂	0.80	0.80	0.86	0.91
N ₂ O	1.00	1.00	1.00	1.00
CH ₄	4.50	8.00	1.00	1.00

How the Correction Factors are Developed:

- **Based on U.S. measurements of comparable technologies.**
- **Limited data to develop correction factors in some cases.**
- **Correction factor established for each vehicle technology and pollutant.**
- **Model contains about 500,000 correction factors.**

How Driving Patterns are Modeled: Considerations

- **Variations in driving can have a profound impact on emissions**
- **It is necessary to develop driving corrections based on easily collected data from a variety of vehicles (this excludes the use of OBD information)**
- **It is difficult to use a defined set of driving cycles for international applications**
- **EPA and others currently searching for a more appropriate method**
- **Affordable, accurate, 1 Hz GPS technology now available**

Vehicle Power Demand

VSP (kW/ton) can be calculated for each second of data using the following equation [Jimenez-Palacios, 1999]:

$$\text{VSP} = v[1.1a + 9.81 (\text{atan}(\sin(\text{grade}))) + 0.132] + 0.000302v^3$$

$$\text{grade} = (h_{t=0} - h_{t=-1}) / v_{(t=-1 \text{ to } 0)}$$

$$v = \text{velocity (m/s)}$$

$$a = \text{acceleration (m/s}^2\text{)}$$

$$h = \text{Altitude (m)}$$

Engine stress is related to vehicle power load requirements over the past 20 seconds of operation and engine RPM:

$$\text{Engine Stress (unitless)} = \text{RPMIndex} + (0.08 \text{ ton/kW}) * \text{PreaveragePower}$$

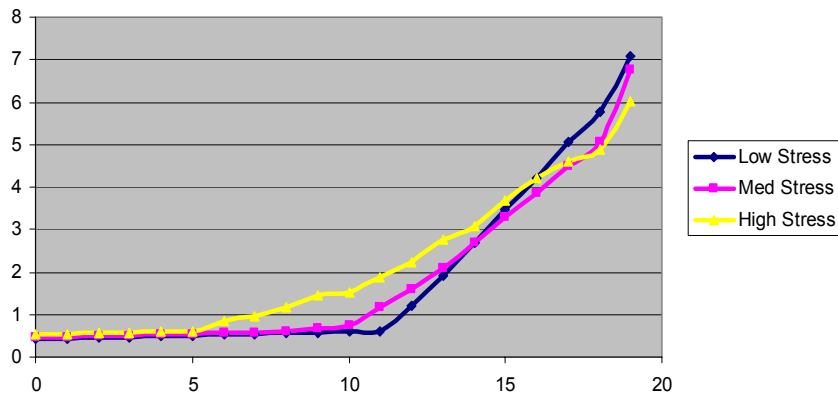
$$\text{PreaveragePower} = \text{Average}(\text{VSP}_{t=-5 \text{ sec to } -25 \text{ sec}}) \text{ (kW/ton)}$$

$$\text{RPMIndex} = \text{Velocity}_{t=0} / \text{SpeedDivider} \text{ (unitless)}$$

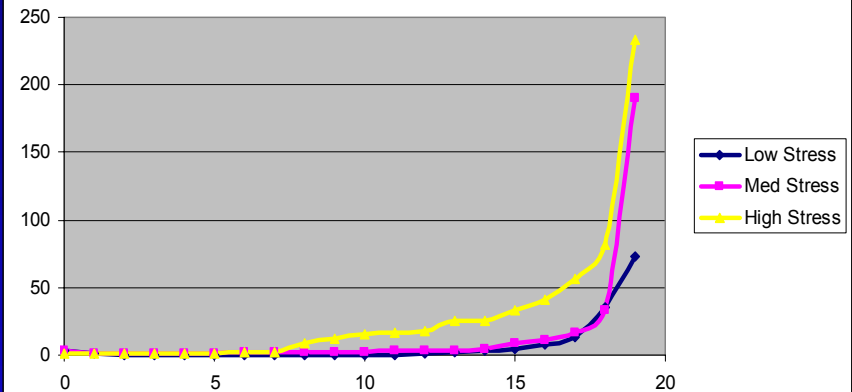
$$\text{Minimum RPMIndex} = 0.9$$

Vehicle Emissions & Power Demand

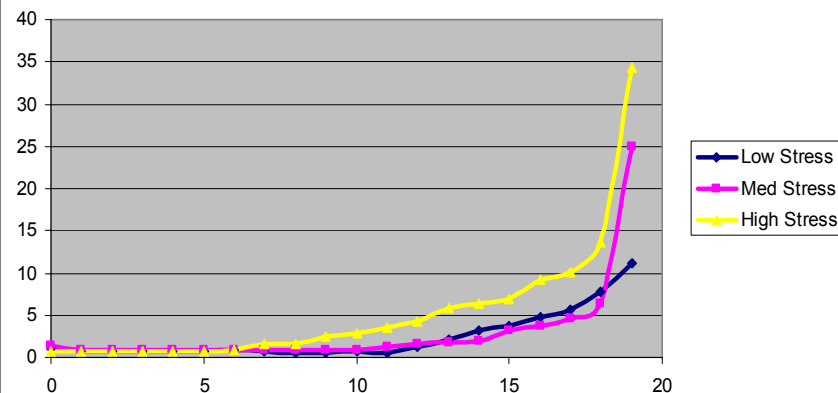
CO2 Emissions Increase Power Curves



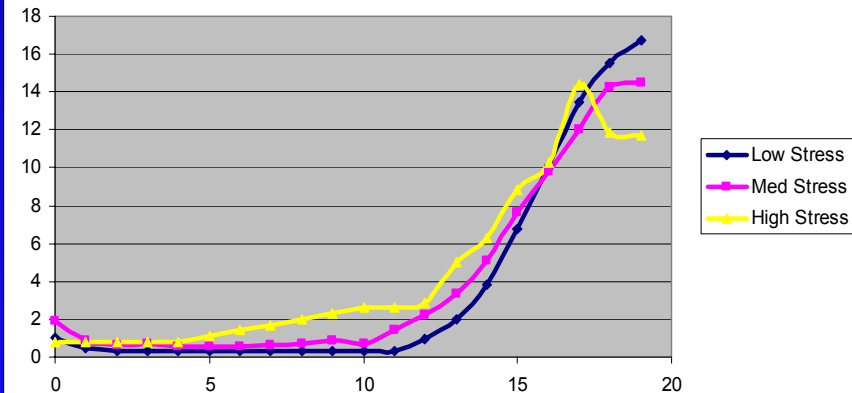
CO Emissions Increase Power Curves



VOC Emissions Increase Power Curves



NOx Emissions Increase Power Curves



Power Bins for IVE Model

- **60 total bins used for model.**
- **3 stress bins and 20 power bins set up to estimate driving impacts on emissions.**
- **60 bin process allows alternative binning modifications in future model improvements.**

Advantage of Power Binning

- **Road grade and air conditioning loads can easily be included in the binning process.**
- **Power statistics easily drawn from measured vehicle speed patterns.**

Determining Vehicle Driving Patterns

GPS / Microprocessor Unit



Battery good for 40 hours of testing.

GPS/Microprocessor Module

Unit easily carried and used to collect bus driving patterns with lid closed.

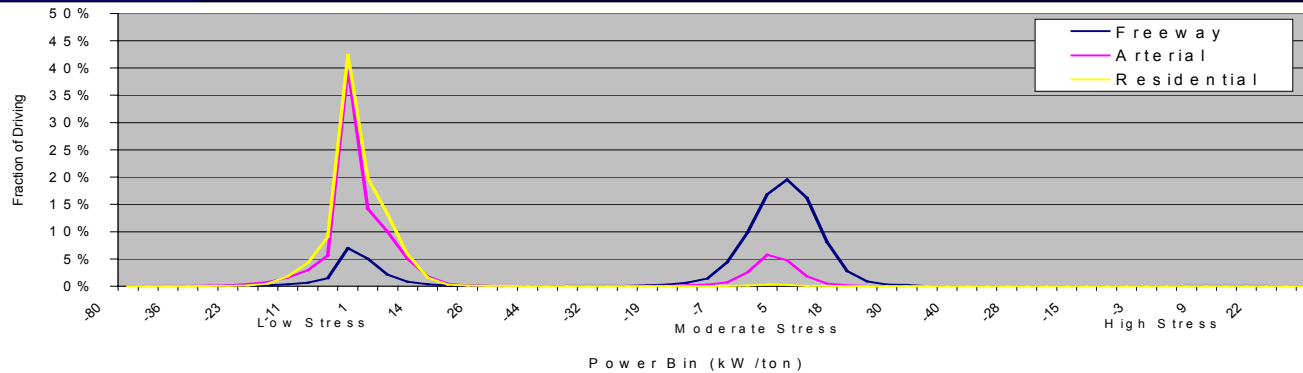


Global Positioning Satellite Units

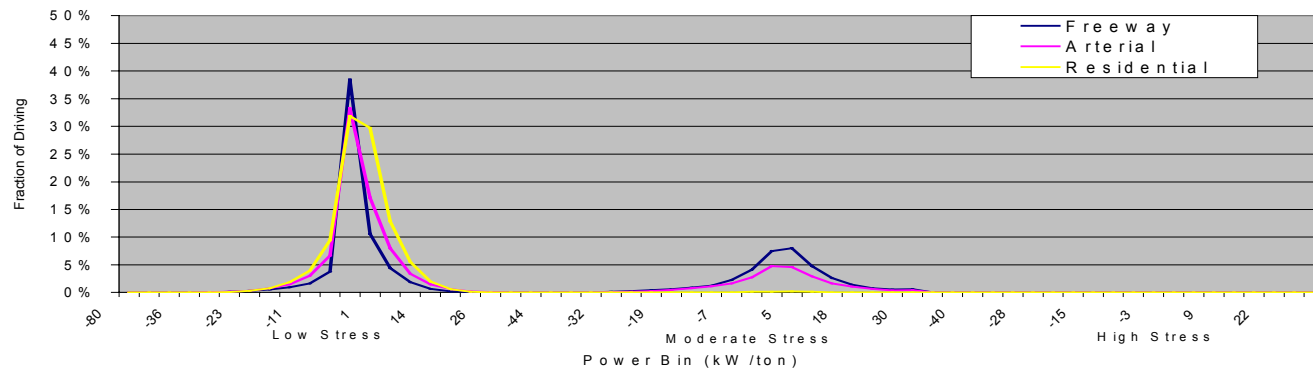
- **Easy to Use**
- **Provide second by second speed, location, and altitude.**
- **Units combined with microprocessor and flash memory to store up to one-week of driving data at a time.**
- **Problems**
 - Loose satellites around tall buildings
 - First 3 seconds of acceleration underestimated but then corrects.

Results: Facility & Location VSP Bin Comparison

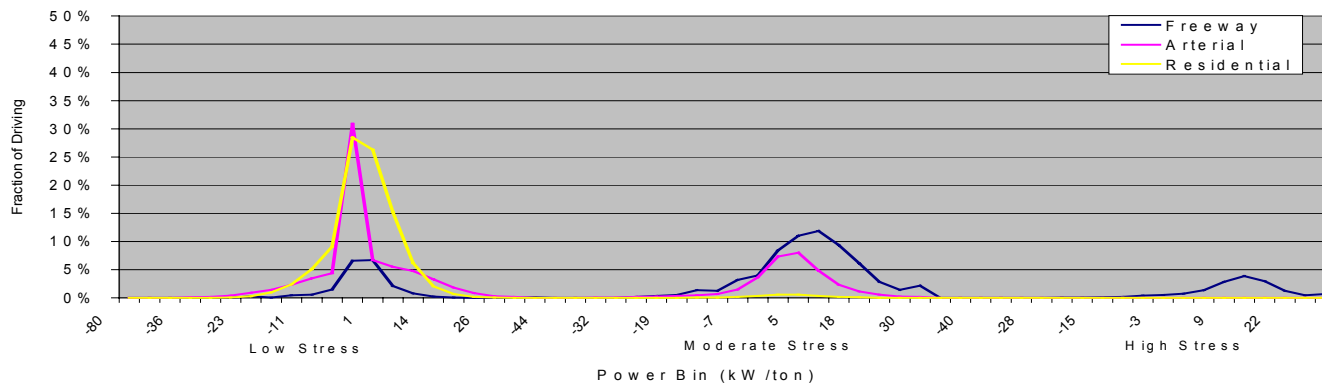
Santiago



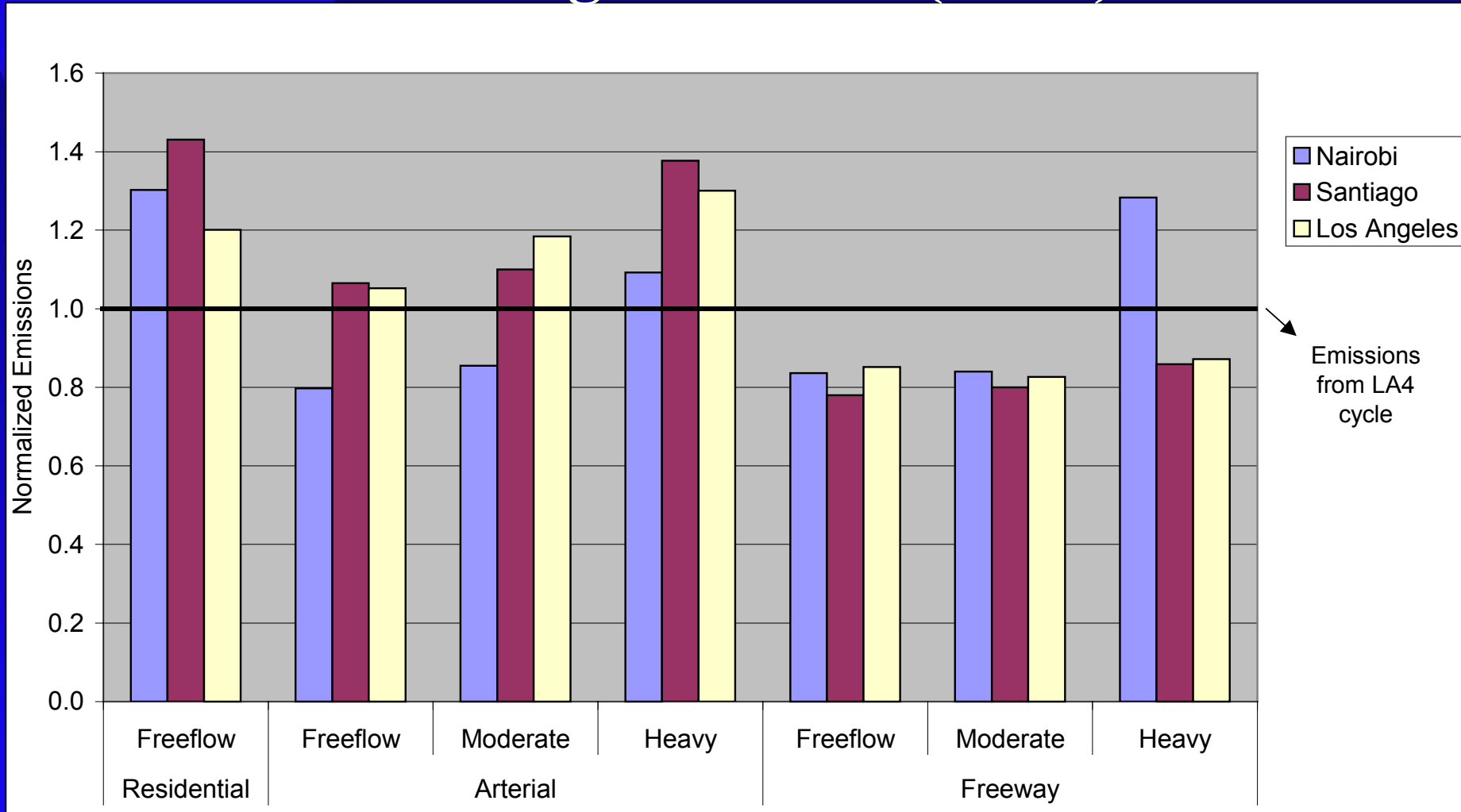
Nairobi



Los Angeles

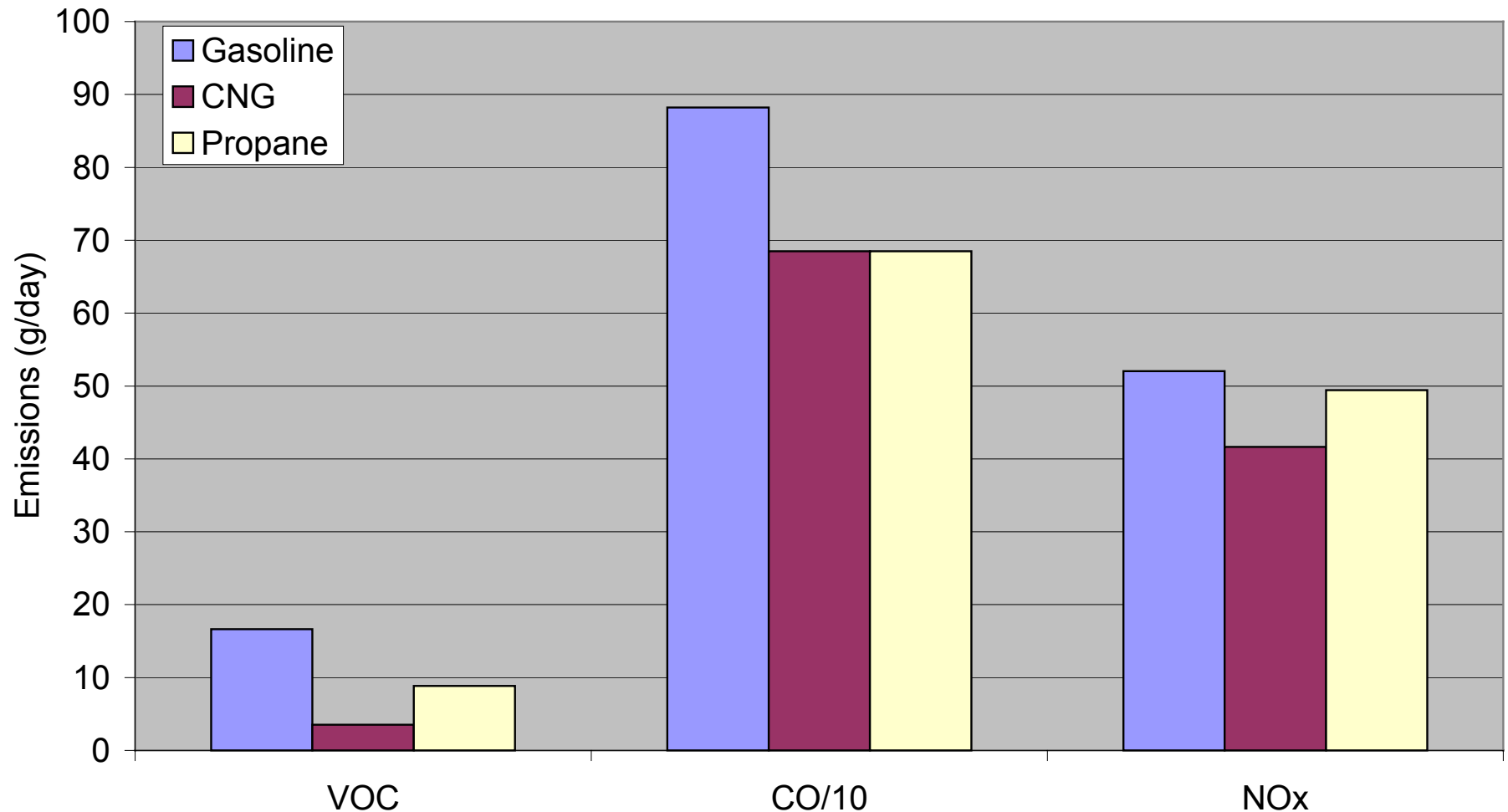


Variation in Emissions of CO₂ with Driving Behavior (LDV)

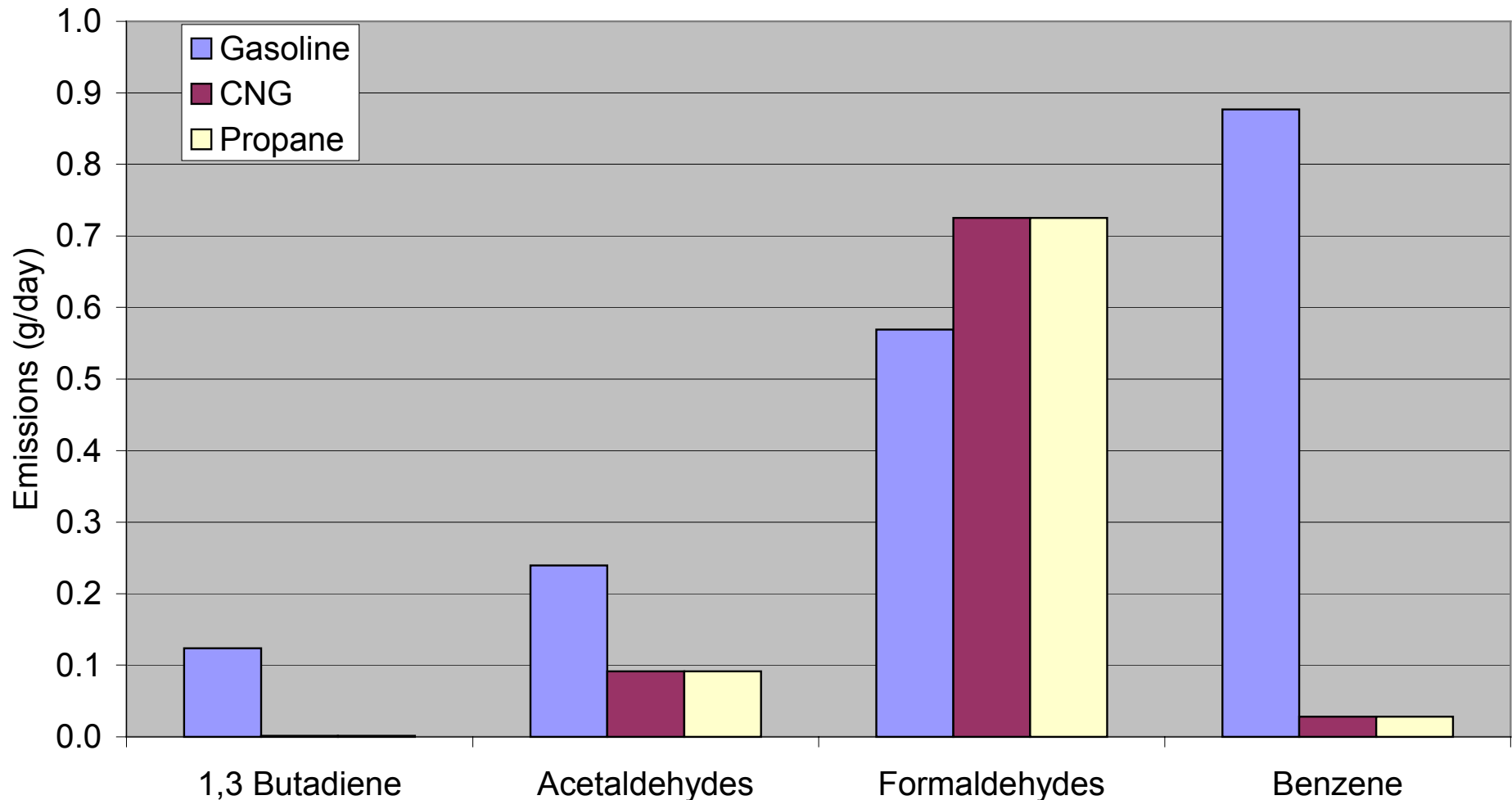


Estimating Emission Benefits from CNG and Propane Vehicles

Example of Propane, CNG, & Gasoline LD Vehicle: Criteria Pollutants



Example of Propane, CNG, & Gasoline LD Vehicle: Toxic Pollutants



Example of Propane, CNG, & Gasoline LD Vehicle: GHG Pollutants

